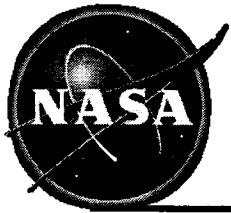


Geoscience Laser Altimetry System (GLAS) On-Orbit Flight Report on the Propylene Loop Heat Pipes (LHPs)

Charles L. Baker (GSFC), Eric W. Grob (GSFC), Thomas V. McCarthy (GSFC),
Michael N. Nikitkin (Swales Aerospace), Walter C. Ancarrow (WCA Inc.)

Abstract. The Geoscience Laser Altimetry System (GLAS) instrument which is the sole instrument on ICESat was launched on January 12, 2003. GLAS utilizes two actively controlled propylene Loop Heat Pipes (LHPs) as the core of its thermal system. The LHPs started quickly when the Dale Ohm starter heaters were powered and have as designed. The low control heater power and on-orbit tight temperature control appear independent of gravity effects when comparing ground testing to flight data. The use of coupling blocks was also unique to these LHPs. Their application reduced control heater power by reducing the subcooling from the radiator. The effectiveness in reducing subcooling of the coupler blocks decreased during flight from ground testing, but internal thermal isolation in the compensation chamber between the subcooled returning liquid increased in flight resulting in no net increase in control heater power versus ground measurements. Overall the application of LHPs in the thermal system for GLAS met instrument requirements and provided flexibility for the overall system as last minute requirements became known.



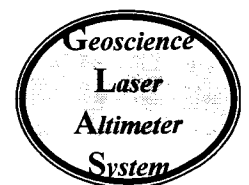
Geoscience Laser Altimetry System (GLAS) On-Orbit Flight Report on the Propylene Loop Heat Pipes (LHPs) International Two-Phase Workshop

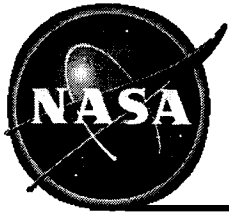
September 15-17, 2003

Charles Baker, GSFC
Eric Grob, GSFC
Tom McCarthy, GSFC
Michael Nikitkin, Swales
Walter Ancarrow, WCA Inc.

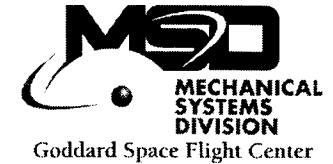
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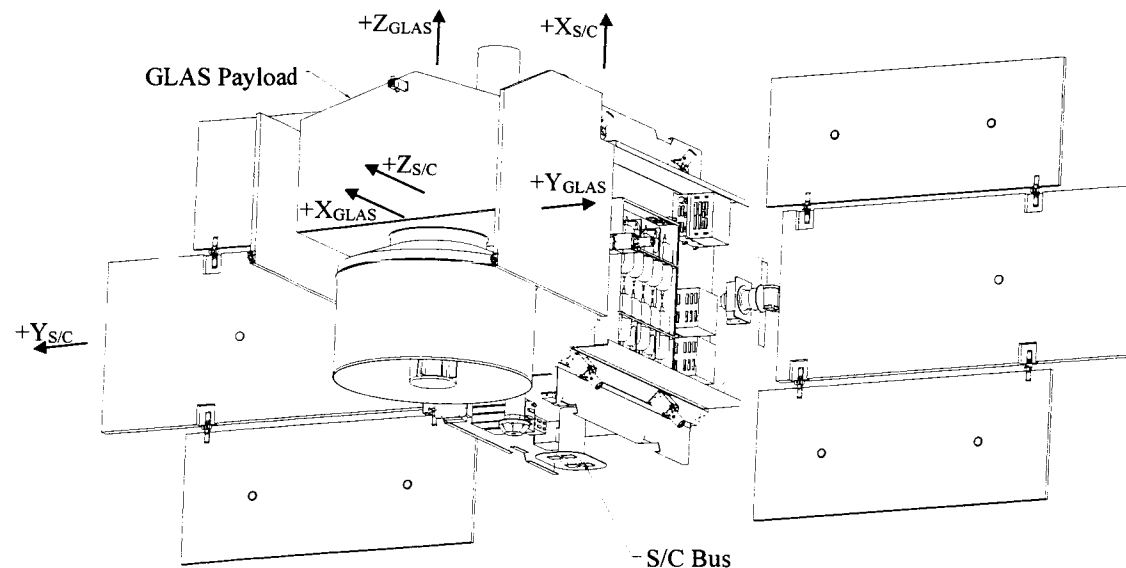




ICESat Mission



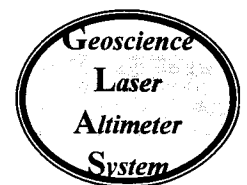
- GLAS is the sole instrument on ICESat, Laser system to measure ice thickness which launched on January 12, 2003
- Orbit - LEO, 600 km, 94° inclination
 - Not sun-synchronous; $\sim 0.5^\circ$ per day precession rate
- SC yaw maneuvers at specific beta angles to maintain array illumination
 - science prohibits continuous yaw steering during data collection
 - numerous thermal attitudes consider

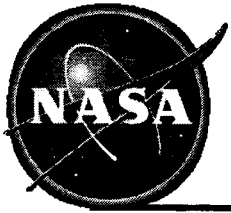


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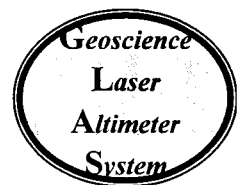
LHPs on GLAS



- These two GLAS LHPs are NASA's first LHP application on a flight mission
- The LHPs are running well and exceeding all of their performance specifications
- These LHPs are the first known US non-military use of Propylene as a working fluid in a flight LHP
- These LHPs are the first known tight temperature control LHPs in-flight
- These LHPs utilize passive coupler blocks to minimize subcooling in the cold case which lowers the required control heater power
- The LHPs on GLAS enabled us to do:
 - Adjust Instrument temperature late in the schedule to resolve a mis-alignment issue - otherwise a risky boresite alignment mechanism would have needed to be added post environment testing
 - Adjustment of the operating temperature within the instrument allows fine-tune alignment of the Instrument optical system
 - Maintain tight control during operation for low control heater power and de-couple the radiators during survival cases

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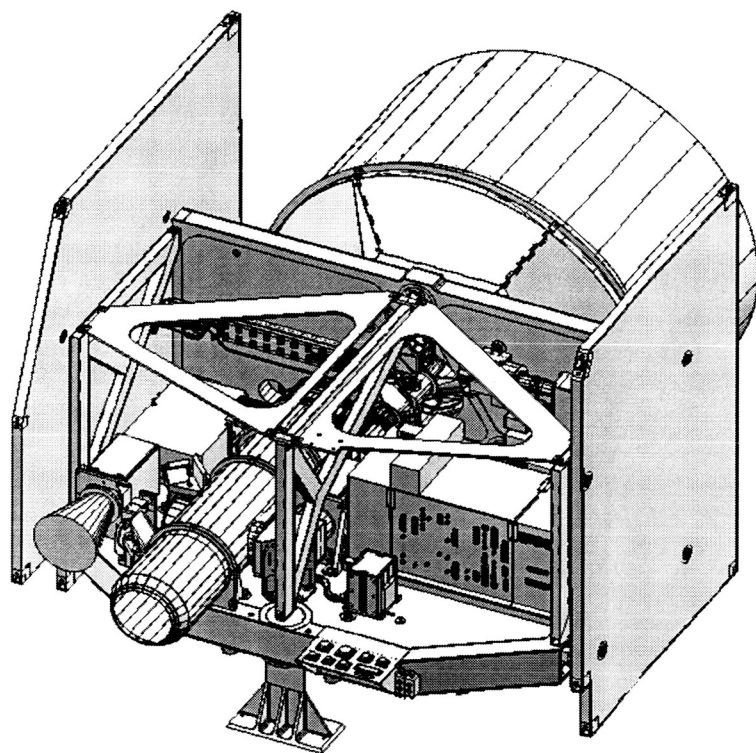




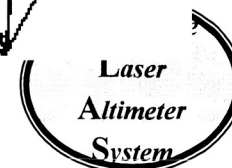
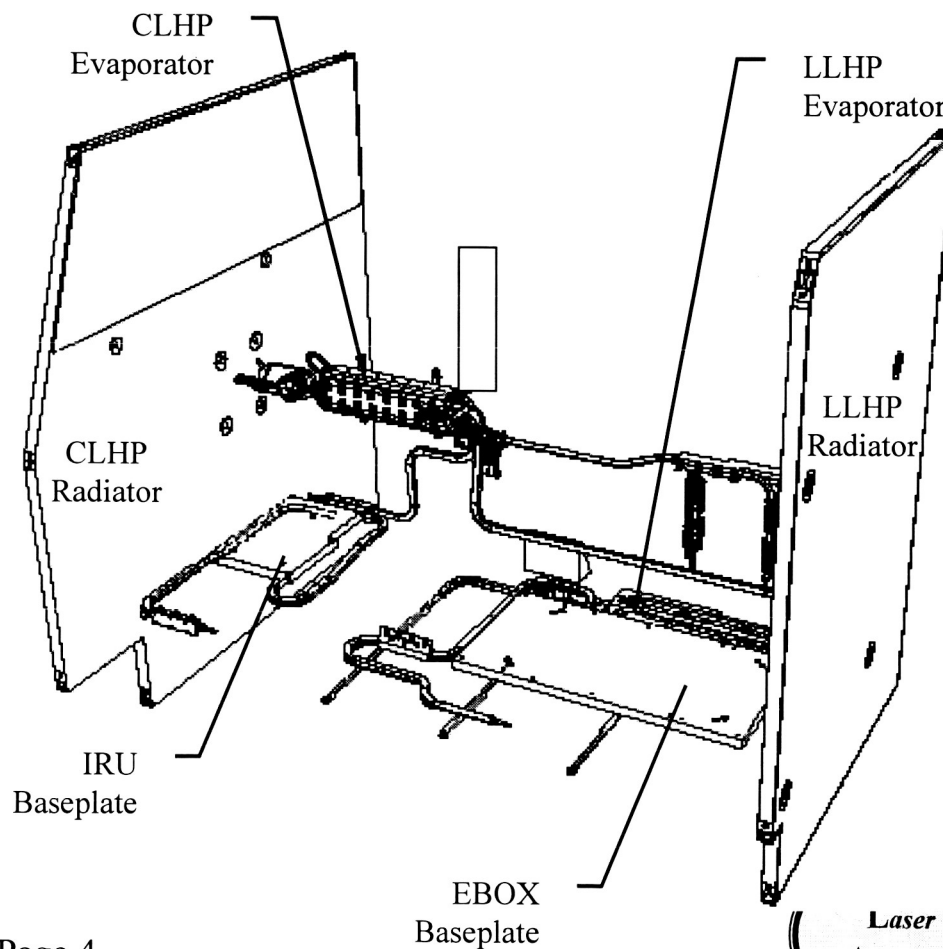
GLAS Thermal Control Subsystem

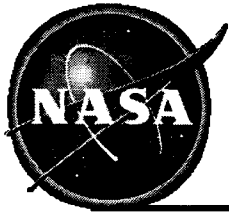


Loop Heat Pipes (propylene): 2
CCHP (ammonia): 10

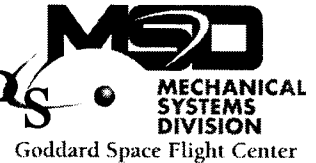


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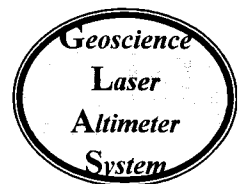




Basic Attributes of the GLAS LHPs

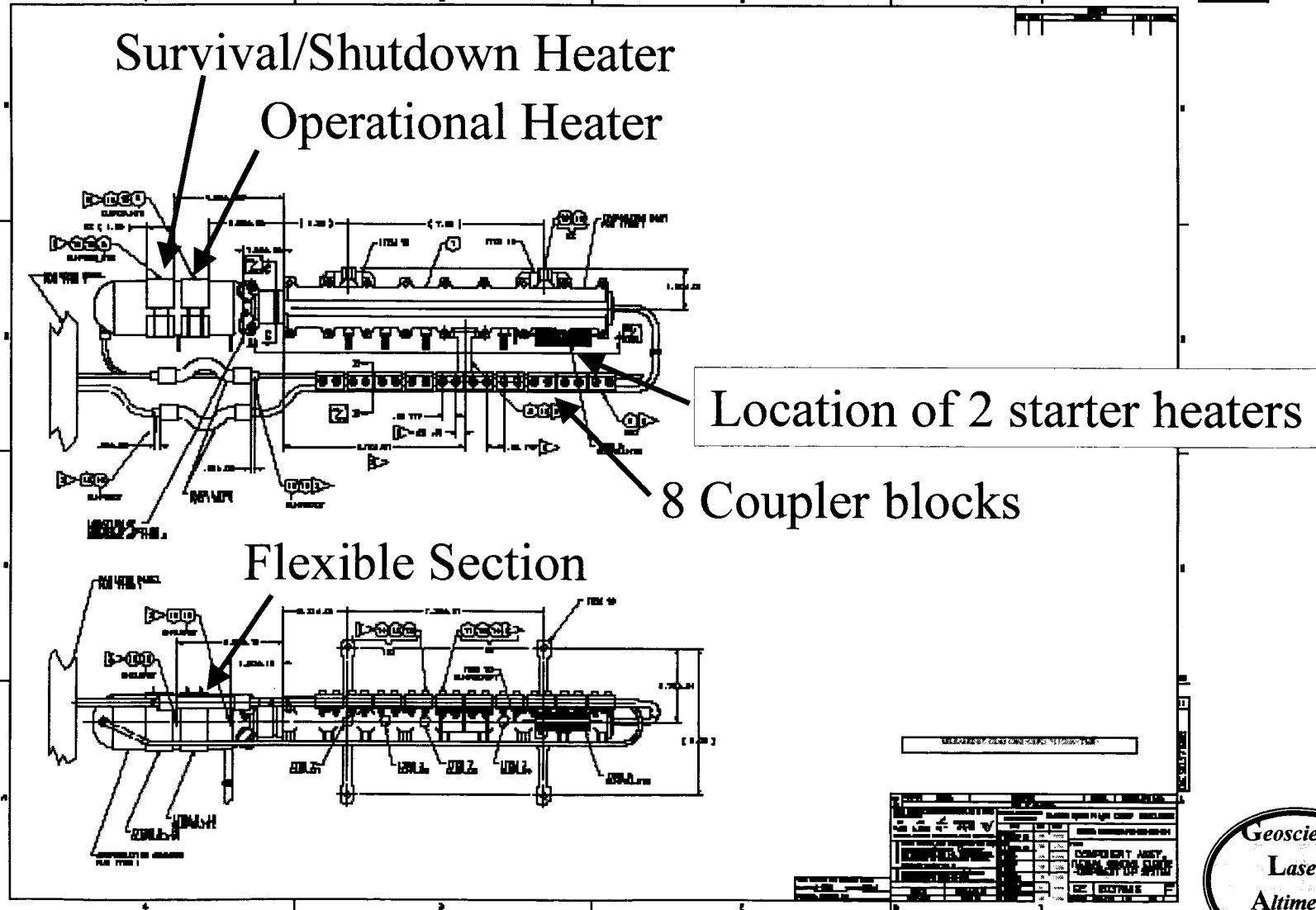


- Propylene is the working fluid so that survival heaters are not required on the radiator (propylene freezes below -120°C)
- LHP System Details:
 - Startup Heaters (Dale Ohm) for startup
 - 58W for 60 Kg of thermal mass CLHP
 - 29 W for 45 Kg of thermal mass LLHP
 - Operational on/off control heaters on compensation chamber are 22 W (used for temperature control)
 - Survival thermostatic heaters for LHP shut down on compensation chamber are 22 W
- LHP Evaporators interfaced directly to a heat pipe network coupling the powered components to the LHP
- 8 - 1" Coupler blocks between the vapor line and liquid line were utilized to reduce the liquid line subcooling and hence reduce required control heater power
- LHPs utilized embedded condenser in the honeycomb radiators



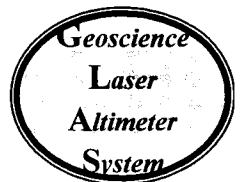


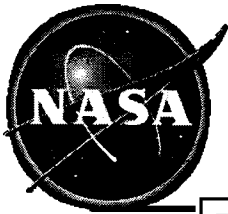
Thermal Instrumentation (CLHP)



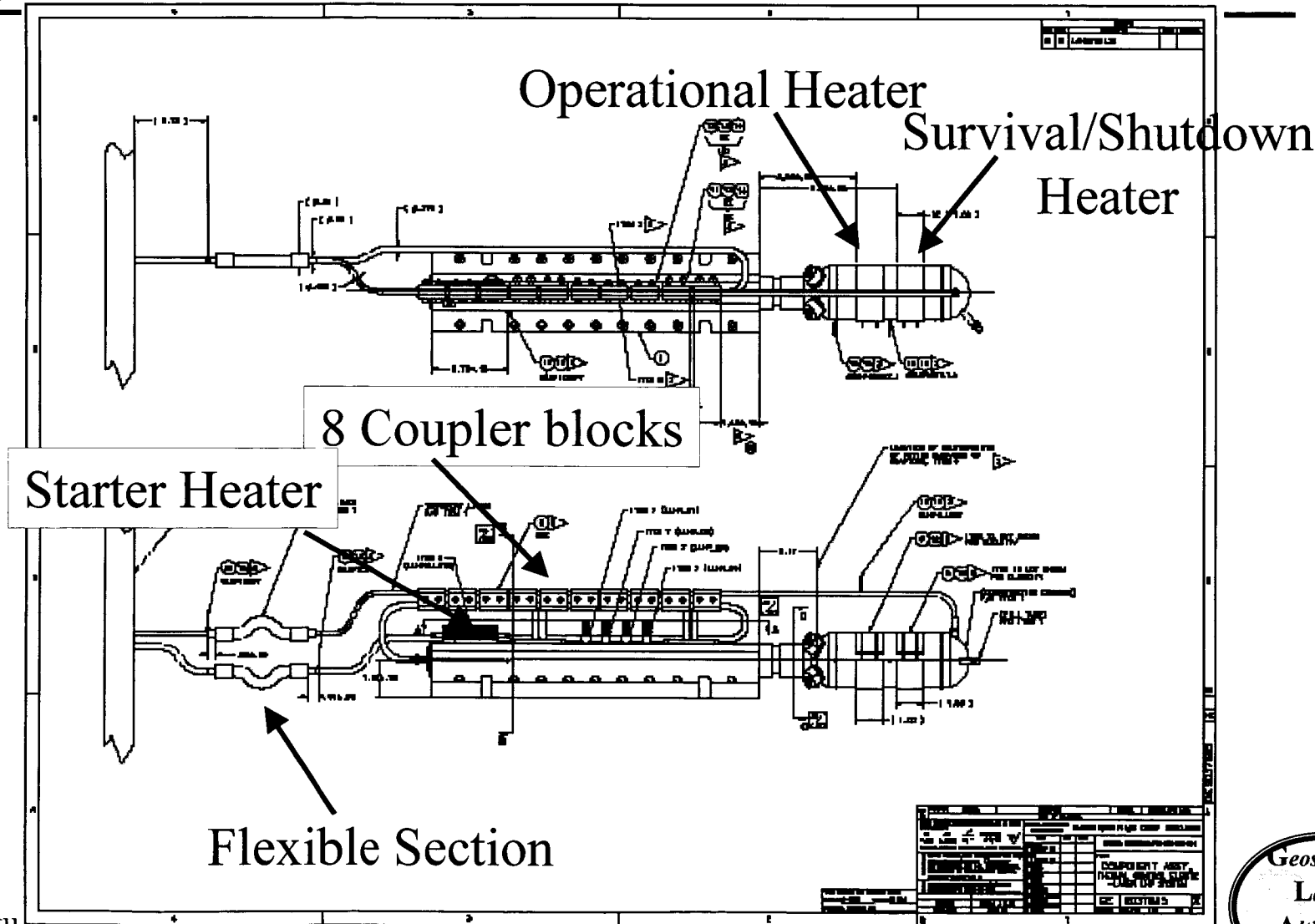
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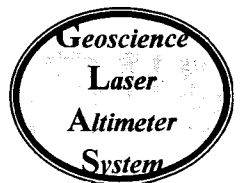


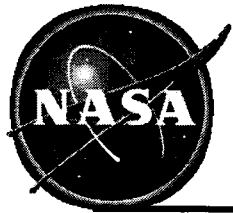
Thermal Instrumentation (LLHP)



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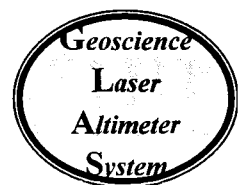




Startup Performance

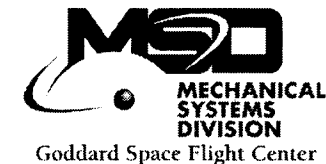


- LHPs did not self-start after launch
- Actual LHP Preconditioning in Flight was “best case” for LHP startup
 - LHPs experienced 18 days of settling time prior to being turned on
 - CLHP had some cold biasing of its compensation chamber due to a view of a cold radiator ($\sim -30^{\circ}\text{C}$) but the CLHPs survival thermostats never were cold enough to click on prior to the LHP starting
 - LLHP’s survival heater had cycled on and off at the beginning of the mission, but when the LLHP was started, the environment was warm enough so that no heaters had cycled for days prior to the LHP starting
- Both LHPs started within minutes of turning on the starter heater after a temperature spike with the evaporator
- The LLHP started without the starter heater later on in the mission but with 45 W of heat

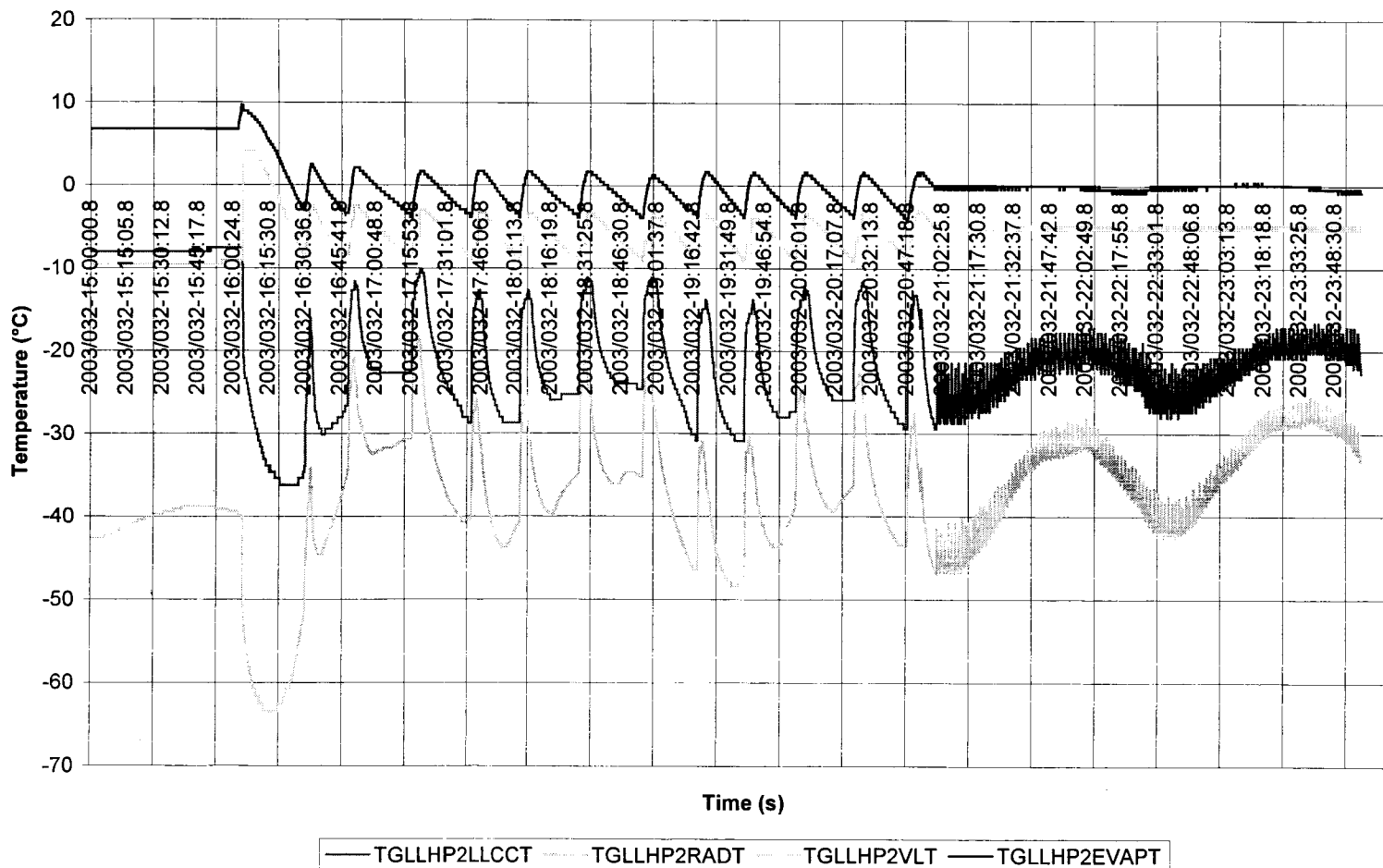




CLHP Startup with 58 W Str Htr



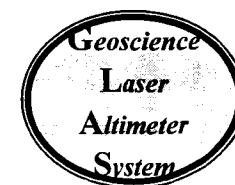
GLAS CLHP Transient Data 02/01/03 (CLHP Turn on)

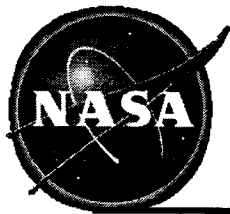


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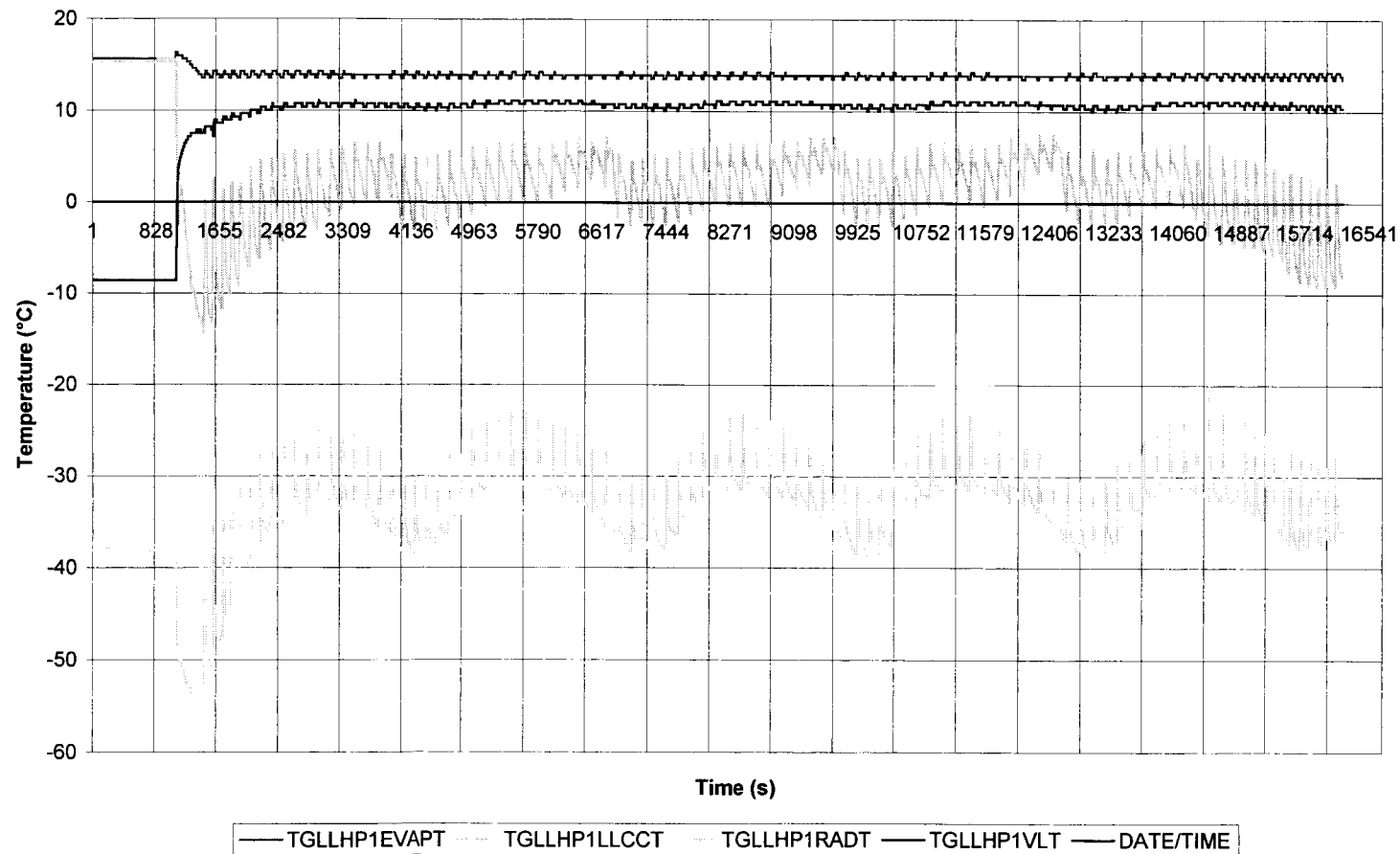




LLHP Startup with 28 W Str Htr

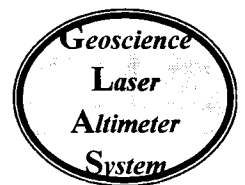


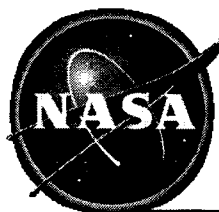
GLAS LLHP Transient Data 02/08/03 (Laser LHP Startup)



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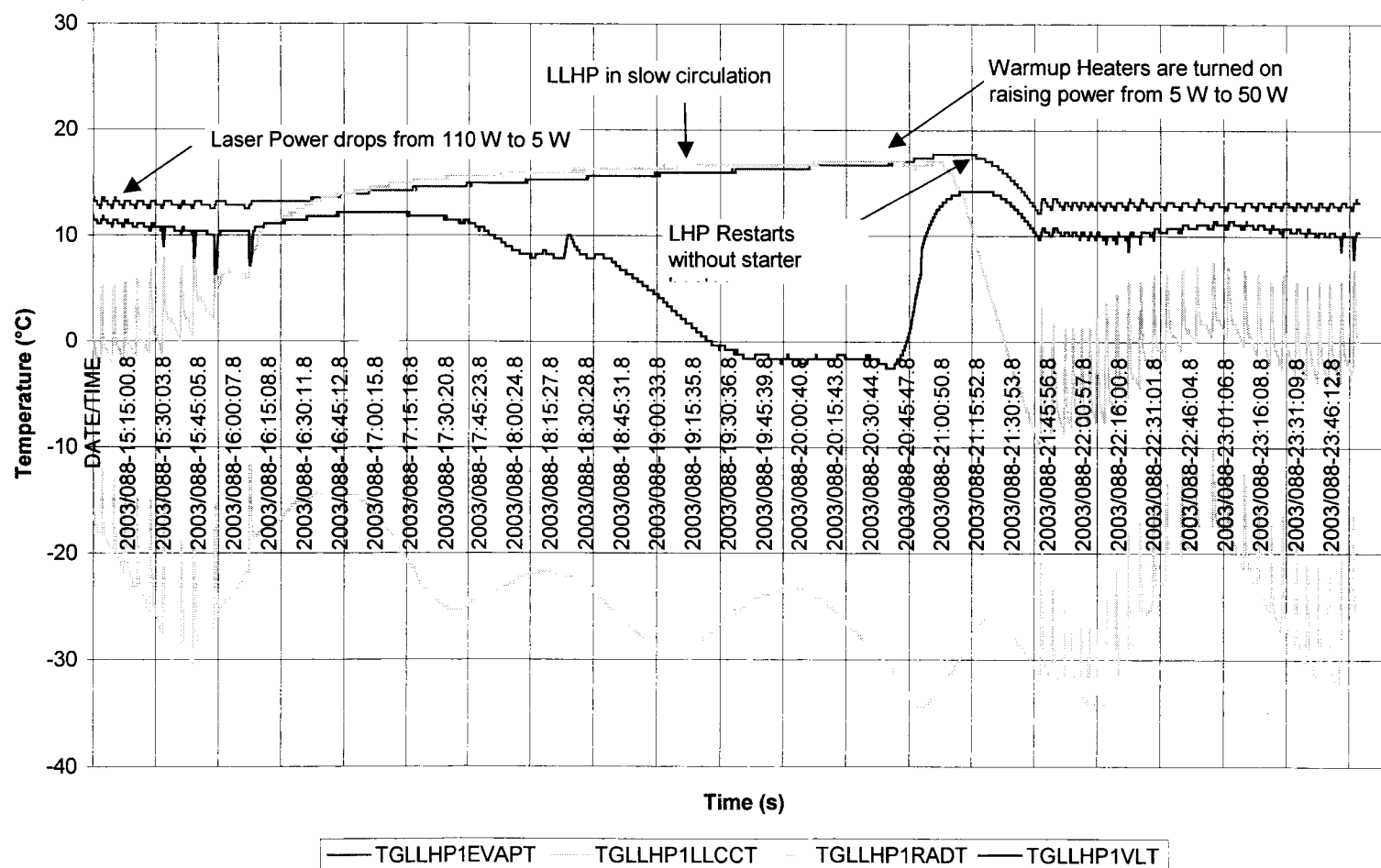




LLHP Startup @ 50 W on Component after slow circulation mode

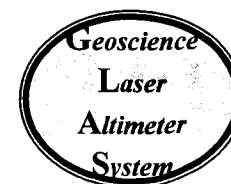


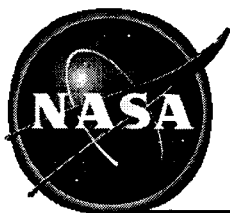
GLAS LLHP Transient Data 03/29/03 (Laser Turn-on, Turn off warmup heaters)



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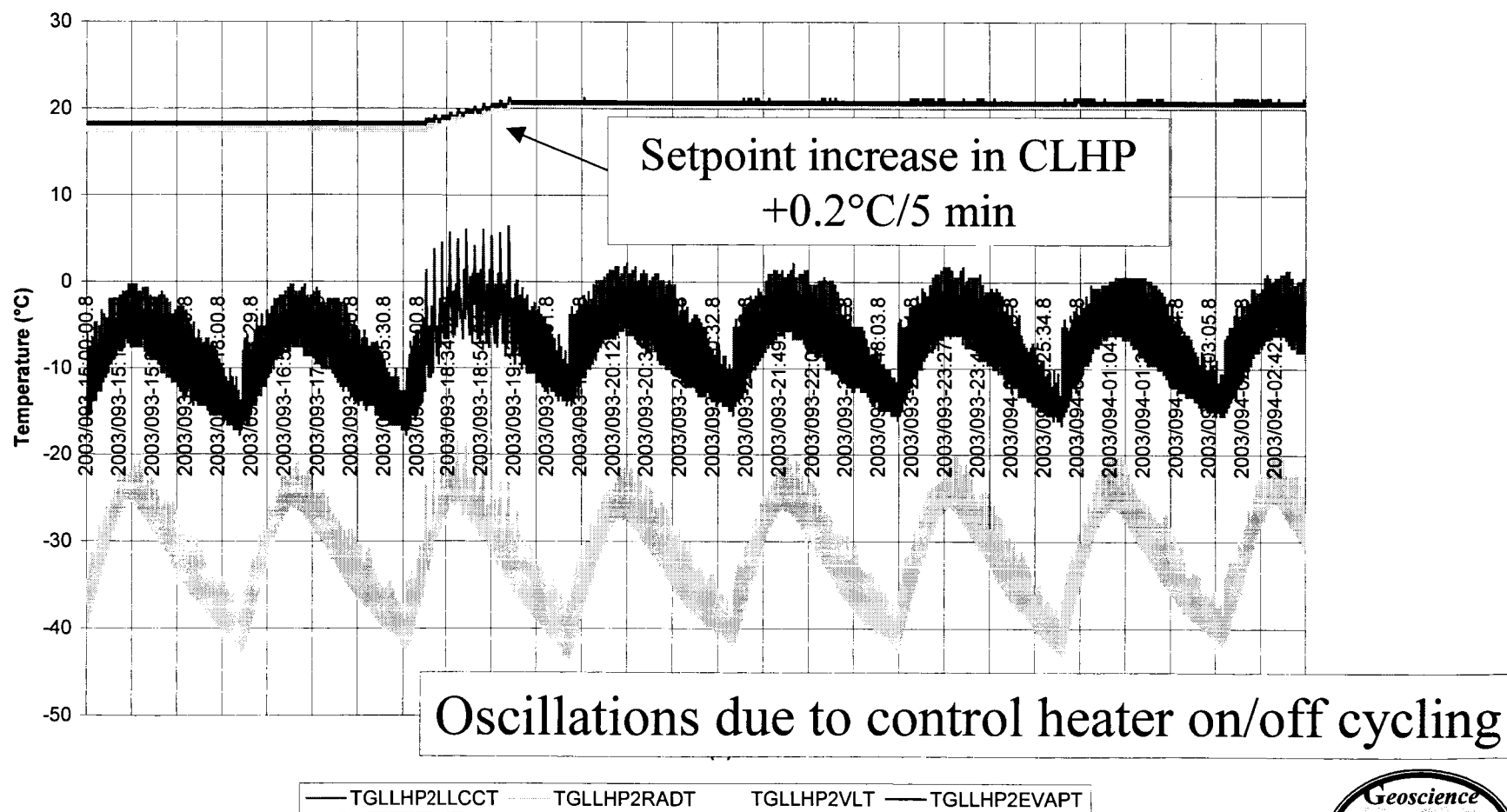




Increasing Setpoints

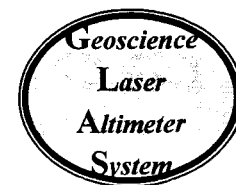


GLAS CLHP Transient Data 04/03/03 (Laser Turn-off, Turn on warmup heaters)



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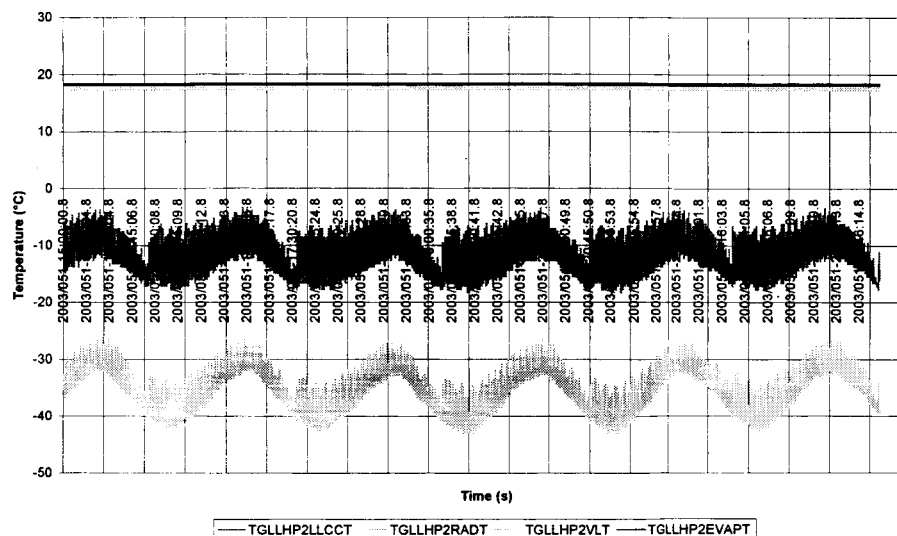




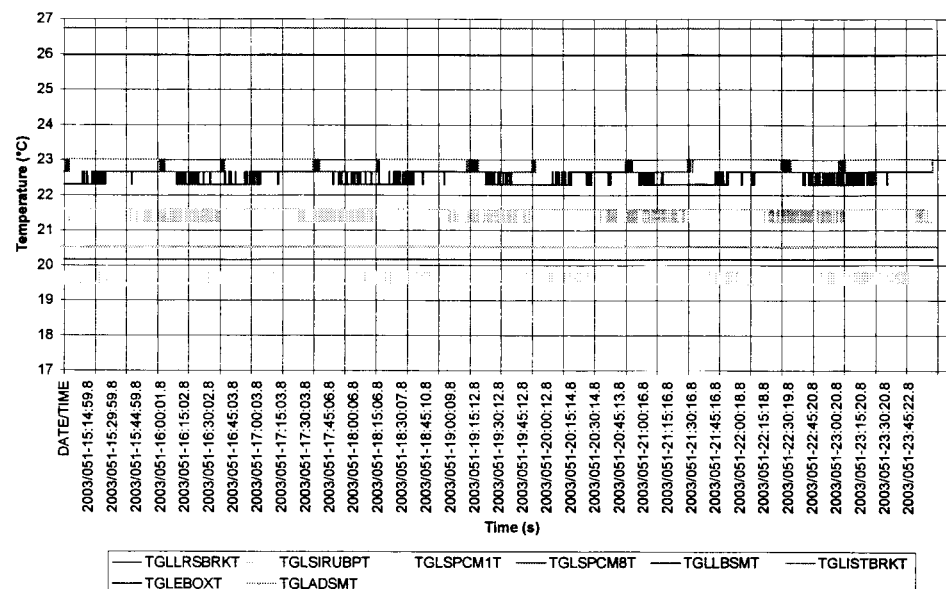
CLHP Control Performance for 143 W System



GLAS CLHP Transient Data 02/20/03 (Laser Turn-on, Turn off warmup heaters, all components powered)



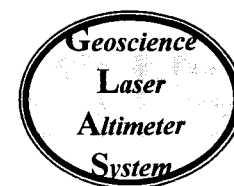
GLAS SC Thermistor Transient 02/20/03 (Laser Turn-on, Turn off warmup heaters)



•CLHP Active Control dampens out radiator transients resulting in a $\pm 5^\circ$ Liquid Return line oscillations to within the less the discretization of the telemetry measurements ± 0.2 per orbit on unblanketed components to unmeasurable on blanketed components

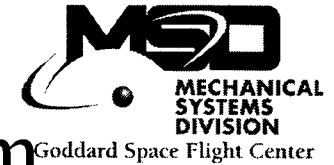
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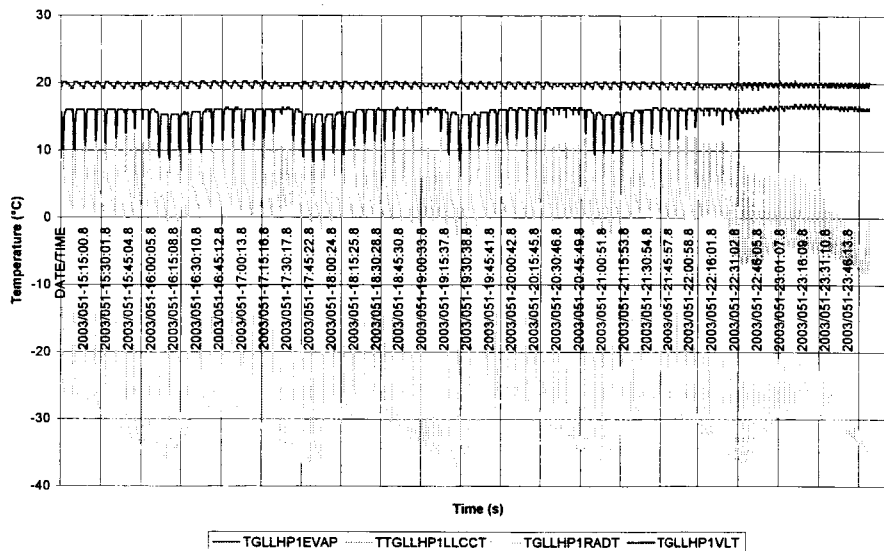




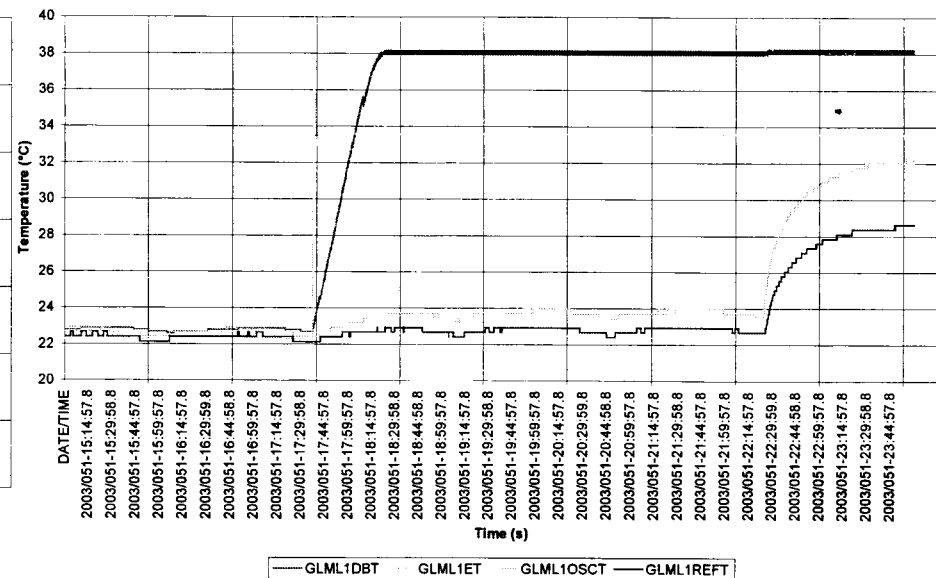
LLHP Control Performance for transition between 45 to 110 W System



GLAS LLHP Transient Data 02/20/03 (Laser Turn-on, Turn off warmup heaters)



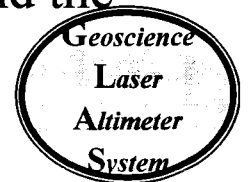
GLAS Laser Transient Data 02/20/03 (Laser Turn-on, Turn off warmup heaters)

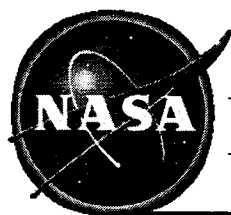


- LLHP Active Control is actually fairly coarse $\pm 0.5^{\circ}\text{C}$ per orbit when the LHP has only 45 W of power input even though the controller has a 0.1°C bandwidth between on and off
- The additional oscillation is due to the time constant between the sensor and the heater

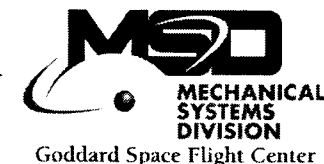
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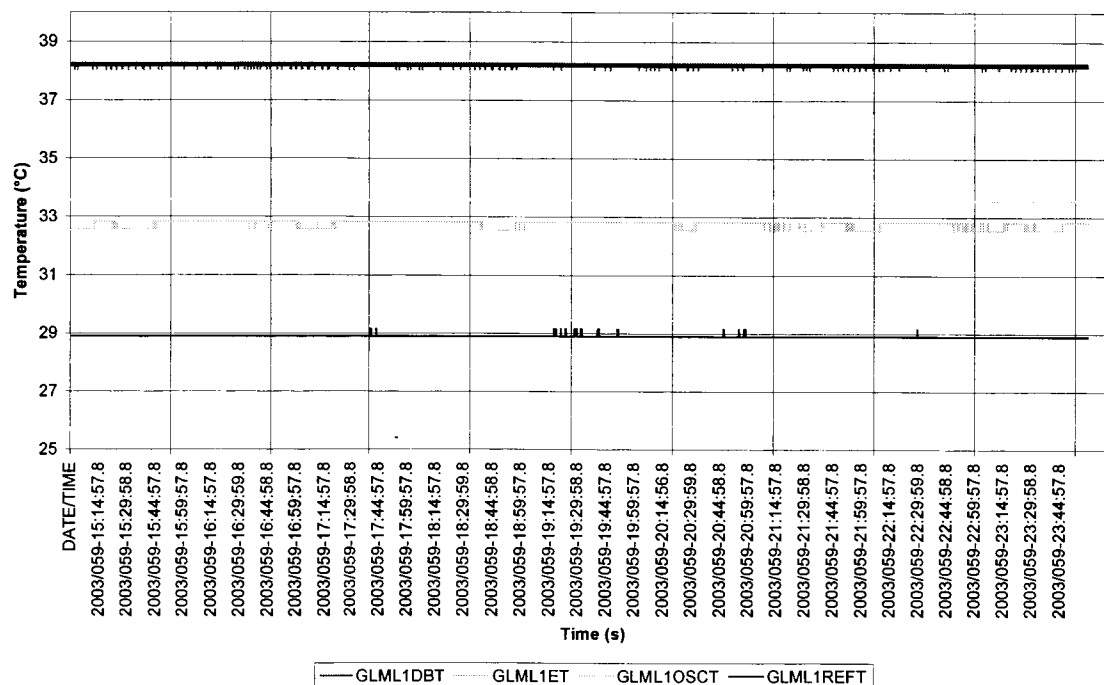




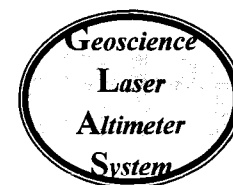
Laser Steady State Control @ 110 W



GLAS Laser Transient Data 02/28/03 (Instrument fully powered)



- LLHP Active Control is finer than can be measured in the laser telemetry when the LHP is at full 110 W of power





Control Heater Power Measurement



Final LLHP Pre-Flight Cases

	Single Mass Power (W)	CC Setpoint (°C)	Thermal Case	Power Measured (W)	Q model calc from return line	Total Subcooling	TC31	TC32	TC32-TC31	TCCC-TC32	Cper block (W/K) where 0.034 is laminar flow
1	120	16.3	Hot/SS		4.2		-23	-1	22	17.3	0.068
2	100	16.9	Cold/SS		5.3		-35	-5	30	21.9	0.056
3	100	32.6	Cold/SS		6.7		-41	5	46	27.6	0.06
4	120.3	16.2	Hot/SS		3.9		-22	0	22	16.2	0.072
5	100	27	Cold/SS		6.3		-43	1	44	26	0.061

Final CLHP Pre-Flight Cases

6	200	10.4	Hot/SS		3.7		-21	-1	20	11.4	0.146
7	129	10	Cold/SS		4.5		-50	-4	46	14	0.123
8	129	15.8	Cold/SS		4.8		-40	1	41	14.8	0.115
9	200	9.1	Hot/SS		3.2		-17	-1	16	10.1	0.139
10	129	10.5	Cold/SS		4.8		-52	-4.5	47.5	15	0.119

Final LLHP Flight Cases

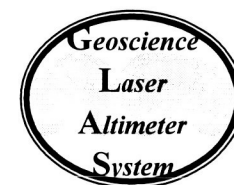
1	2003/051	45	19.5	B=-44		4.0		-28	3	31	16.5	0.033
2	2003/059	110	19.5	B=-41		5.4		-29	-3	26	22.5	0.058
3	2003/079	110	19.5	B=-34		5.4		-27	-3	24	22.5	0.055
4	2003/082	110	19.5	B=-33		4.5		-21	1	22	18.5	0.063
5	2003/091	45	12.5	B=-30		1.3		-21	7.2	28.2	5.3	0.029

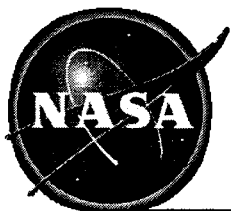
Final CLHP Flight Cases

1	2003/051	143	17.8	B=-44		9.6		-35	-12	23	29.8	0.051
2	2003/059	143	17.8	B=-41		9.6		-35	-12	23	29.8	0.051
3	2003/079	143	17.8	B=-34		9.3		-35	-11	24	28.8	0.055
4	2003/082	143	17.8	B=-33		8.9		-31	-10	21	27.8	0.052
5	2003/091	143	17.8	B=-30		8.6		-32	-9	23	26.8	0.057

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Effectiveness of Coupler Blocks on Reducing Control Heater Power



- If the flow thru the liquid line is assumed to be laminar (meaning that the mass flow rate is stable) the calculated conductance thru each block would be 0.034 W/K
- This number corresponds well to the LLHP when it is operating at 45 W (note this page's numbers are taken from the chart on the proceeding page)
- The flight effectiveness of the Coupler blocks is lower indicating closer to laminar flow than ground with 1-g effects
- The coupler blocks essentially reduce the subcooling by about half

Flight
(W/K)

Cperblock	
0.033	
0.058	mean
0.055	0.0476
0.063	std dev
0.029	0.015485

LLHP

On-Ground Testing
(W/K)

Cperblock	
0.068	
0.056	mean
0.06	0.0634
0.072	std dev
0.061	0.006465

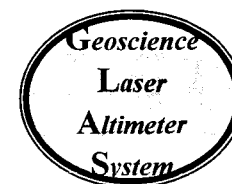
CLHP

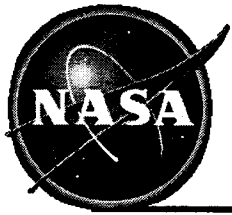
Cperblock	
0.051	
0.051	mean
0.055	0.0532
0.052	std dev
0.057	0.002683

Cperblock	
0.146	
0.123	mean
0.115	0.1284
0.139	std dev
0.119	0.013409

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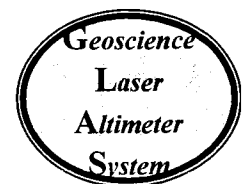


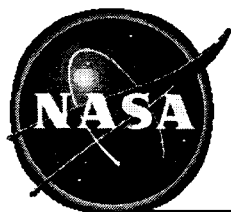


Control Heater Power Required Test to Flight



- Despite the blocks being less effective in flight, the overall control heater power was about the same as on the ground when comparing similar cases i.e CLHP power measured comparison of Beta angle 33 before the yaw (Hottest attitude) at 4 W versus Hot/SS at Hot/SS around 3.7 W
- Because the blocks are less effective and the heater power is the same, it must mean the liquid return line is better insulated from the 2-phase bubbles in the compensation chamber during 0-g Flight versus 1-g test which results in:
 - less of the subcooling power being transferred to the compensation chamber thru condensing vapor bubbles
 - therefore due to conservation of energy, most of the subcooling is entering the wick and being sensibly heated to saturation temperature before evaporating





Heat Pipe + LHP Conductance Test to Flight

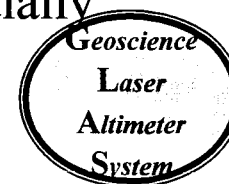


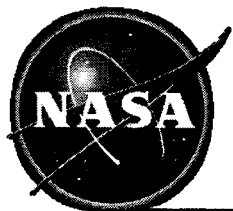
MDT	dT from CLHP temp	dT from LHP CC temps	Percentage Decrease
	Flight	Hot Soak Observatory	(%)
SC thermistors			
TGLISTBRKT (Star Tracker Brackt)	5.4	6.5	17%
TGLLRBRKT (LRS Brackt)	9.4	11.3	17%
TGLSPCM1T (Lidar Det SPCM 1)			
TGLSPCM8T (Lidar Det SPCM 8)			
TGLLHP1EVAPT (LLHP Evap)	0.3	2.2	86%
TGLLHP2EVAP2 (CLHP Evap)	0.4	0.9	50%
TGLSIRUBPT (IRU Base)	3.8	5.5	31%
TGLEBOXT (MEU base)	8.6	10.5	18%

- Heat Pipe conductances improved from ground testing due to the better liquid feeding of the grooves in the absence of gravitational forces by about 17%
- It also appear that the LHP conductances have improved since the dT has decreased between the evaporator and compensation chamber, but insufficient flight instrumentation (particularly on the heat pipe headers) prevents an accurate statement of how much they improved
- Evaporator Conductance: ~24 W/K for DM LHP as compared to 35 to 40 W/K for the flight units (in 1-g testing) though not expected to substantially change in flight

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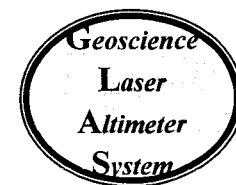
Hot versus Cold Case Performance



- Component temperatures that are linked via the heat pipe network are independent to the thermal environment of the radiators
- Control heater power does decrease as the condensers warm up

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Conclusion



- Use of Propylene LHPs for the GLAS instrument was a good choice for tight control and diode action required for the system
- The LHPs were flexible for late changing requirements
- No major changes between in-flight and on-ground performance

